

Bedform Parameterization and Object Detection From Sonar Data- Application of Finger Print Algorithms

PI: Arthur C. Trembanis
CSHEL

<http://cshel.geology.udel.edu/CSHEL/>

College of Earth, Ocean, and Environment

University of Delaware

109 Penny Hall

Newark DE, 19716

phone: (302) 831-2498 fax: (302) 831-4158 email: art@udel.edu

Co-PIs: Larry Mayer and Jonathan Beaudoin

Center for Coastal and Ocean Mapping

University of New Hampshire

Durham, NH 03824

Phone: (603) 862-2615 fax: (603) 862-0839 email: larry@ccom.unh.edu

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LONG-TERM GOALS

The long-range goals of this research are to improve our ability to characterize the seabed geometry and texture in energetic inner-shelf/bay mouth settings composed of heterogeneous sedimentary material with dynamic seabed ripples. Our purpose is to improve our understanding of bedform dynamics and spatio-temporal length scales and defect densities through the application of a recently developed finger print algorithm technique (Skarke and Trembanis, 2011) in the vicinity of manmade seabed objects and dynamic natural ripples on the inner shelf utilizing high-resolution swath sonar collected by an AUV and from surface vessel sonars in energetic coastal settings with application to critical military operations such as mine countermeasures.

OBJECTIVES

The objectives of this project are a sonar based (platform independent) bedform parameterization and acoustic object detection system applicable to the spectrum of coastal and estuarine settings.

The following are the specific objectives of this research:

1. Conduct a local field experiment at the Redbird Reef, DE dump site (objects include tires, military vehicles, shipwrecks, and over 900 former NYC subway cars) to measure, over the extent of the field site, object scour evolution, morphodynamic behavior, sediment texture, and bedform characterization through remote sensing techniques.

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2. Extend and apply recently developed finger print algorithm techniques (Skarke and Trembanis, 2011) for ripple parameterization and object detection using AUV, ship, and rotary sonar derived backscatter and bathymetry data.
3. Extend the ARA system developed by UNH into energetic and heterogeneous shelf settings; particular the abundance of variously sized manmade objects will provide a unique testing set for ARA remote classification techniques

APPROACH

Our approach has been to obtain a suite of field observations by performing carefully repeated high-resolution seafloor mapping over a natural seabed system approximately 1-2 km's on a side including areas with dynamic ripple bedforms and manmade structures. We have gathered: (1) optical imagery and acoustic backscatter of surface sediment layers from an autonomous underwater platform and from surface vessel multibeam echosounder sonar; (2) small scale (sub-meter) bathymetry and morphology from a small maneuverable AUV platform, and; (3) further developed a remote acoustic segmentation and classification system (ARA) for bathymetry and backscatter data collected by the AUV. We have also deployed and maintained a bottom-moored instrument package with an ADCP (waves and current) and rotary sonar (2D ripple) for time-series measurements of hydrodynamics and small-scale bedform dynamics (*sensu* Skarke and Trembanis, 2011). The fusion of these remotely sensed data (hydrodynamics and morphology) with ground truth samples and the ARA remote acoustic model will be used to improve our understanding of the response of the seabed to mean and oscillatory flows (tidal and wave driven respectively) and the interpretation of acoustic imagery for surface textural properties of surficial sediments on the seabed in other settings.

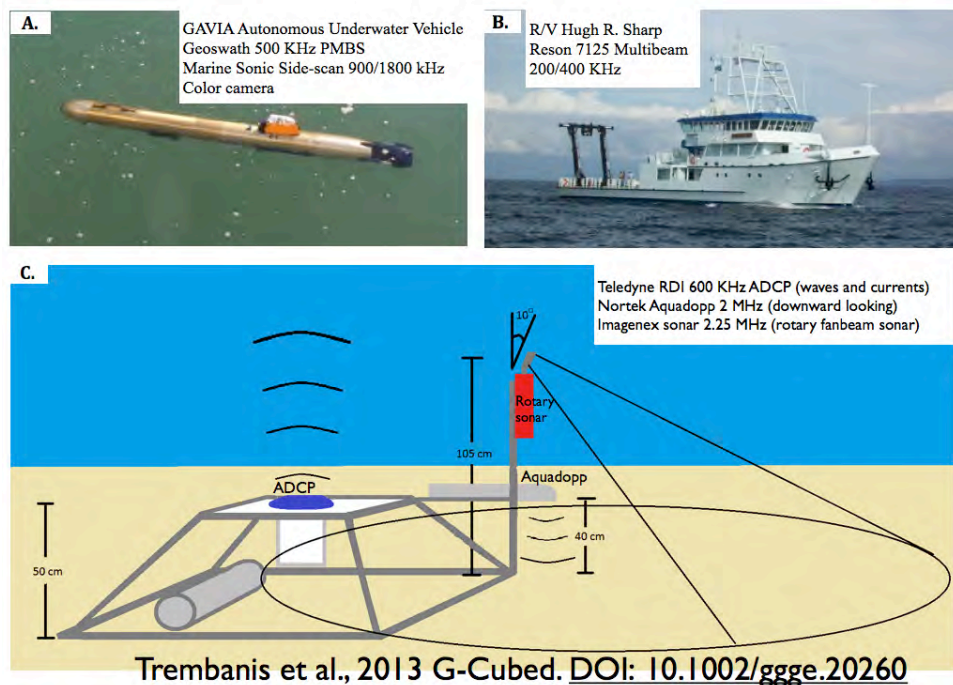


Figure 1- Project sensor systems. Reprinted from Trembanis et al., 2013

WORK COMPLETED

The following section highlights the major research accomplishments from this project over the last year

- G-cubed research letter Trembanis et al., 2013 ([DOI: 10.1002/ggge.20260](https://doi.org/10.1002/ggge.20260))
- Repeated cruises- mapping the field site- October (3 days before hurricane Sandy), November (11 days after Sandy), December (recovery 1 month), March (following spring nor'easter), July (8 month recovery), November (planned)
- Hydrodynamic sensor deployments (ADCP & HR Aquadopp ADP) -Aug-Sep 2012, Oct-Nov 2012, March-June 2013, July -Oct 2013 (ongoing)
- 2 online features news articles
- 4 public presentations of project results including 3 invited seminars
- Project providing data for 4 different graduate student theses

Research Cruise Planning and Execution

The research team conducted several in person project planning meetings and remote meeting sessions in order to prepare the cruise and field deployment plans. A detailed field survey campaign was developed and submitted for ONR approval (received September 2012). Of particular note is that fact that as our first cruise date approached in October 2012 it was apparent that hurricane Sandy was on track to approach the field site. We then worked with the operations personnel of the R/V Hugh R. Sharp who were tremendously flexible and supportive of our efforts and this allowed us a unique opportunity to get out and conduct our initial site surveys on about October 26th just 3 days before the landfall of hurricane Sandy. The ship's crew is to be commended as they pushed the cruise till as late and as long as they could before having to return to shore and prepare the ship for safe anchorage during the hurricane. This unexpected but serendipitous occurrence provided a truly unique and added benefit to our project. Immediately after completing the initial pre-Sandy survey we discussed with the R/V Sharp personnel the prospects of a post storm survey. Again the crew was extremely receptive and supportive and we were able to get back out on the first available cruise, a mere 11 days after hurricane Sandy made landfall. The particularly unique before and after hurricane Sandy multibeam sonar mapping datasets provided the basis of a manuscript by the project science team that has just been published by the journal *Geochemistry, Geophysics, and Geosystems* (G-Cubed) entitled "A detailed seabed signature from hurricane sandy revealed in bedforms and scour" (DOI: 10.1002/ggge.20260)

Ship Multibeam Component

A 1.0 x 0.5 km area was surveyed in detail on 5 separate repeated occasions (October 2012, November 2012, December 2012, March 2013, and July 2013) using a Reson 7125 SV2 system deployed on R/V *Hugh Sharp* (Figure 2). The 7125 system provided both detailed bathymetry and seabed imagery/backscatter. The surveys were repeated at least twice during each cruise using both the 400 kHz and the 200 kHz sonar setting in order to assess the impact of sonar system configuration on the ability of the fingerprint algorithm to detect seabed bedform features and also to utilize these data for acoustic classification via Angular Range Analysis (ARA). The first survey cruise allowed us to test and optimize the system configuration for bathymetric resolution whereas the subsequent surveys focused on precisely repeated the sonar data surveys. The multibeam system was operated at 400 kHz for the greater resolution available in this configuration: the 1.0° x 0.5° beam width for transmit/receive allowed for spatial resolution on the order of 0.5 m x 0.25 m in water depths of 27 m for the near nadir beams. Raw GPS measurements were recorded from an Applanix POSMV 330 (V5) and were post-processed using Applanix POSPac MMS to reduce horizontal and vertical positioning

uncertainties. By recording the GPS measurements, the data was post-processed to allow for improved accuracies based on knowledge of the satellite constellation orbits, clock corrections, atmospheric delays, etc. Vertical positioning provided by the POSMV allowed for an ellipsoidal reference; removing uncertainties associated with poor tidal knowledge offshore, heave sensor limitations and variations in draft/squat of the vessel between surveys. Vertical repeatability between surveys is on the order of 10-15 cm.

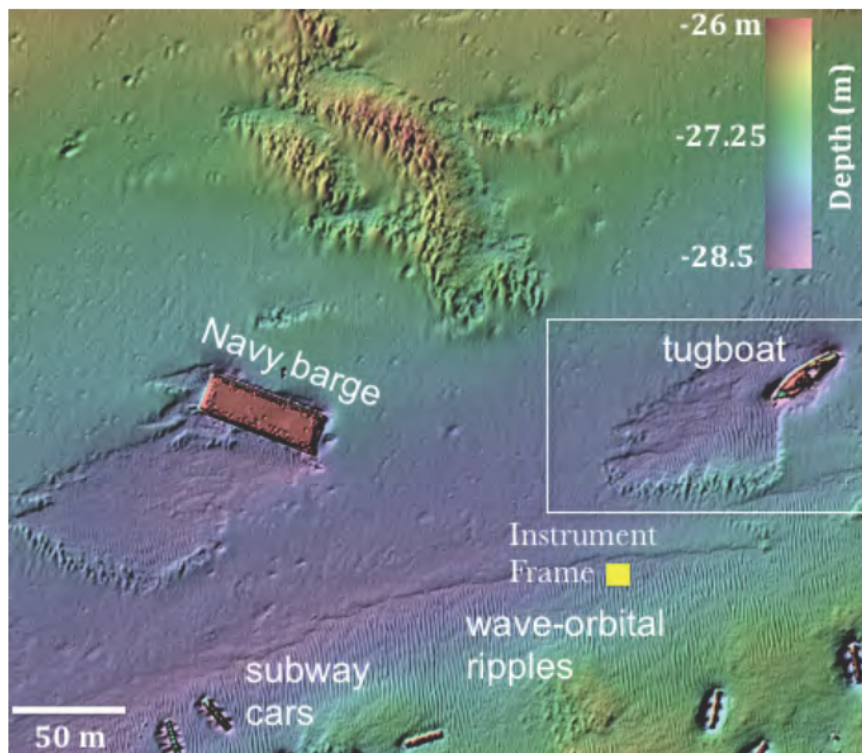


Figure 2. High-resolution 25cm/pixel bathymetric map of the Redbird reef field-site. Location of bottom mounted instrument frame noted by yellow square. Figure reprinted from recently published project paper (Trembanis et al, 2013 G-Cubed. DOI: 10.1002/ggge.20260

Bottom Mount Instrument Deployments

In addition to the surficial mapping activities our cruise work has included the deployment of hydrodynamic sensors on a seabed instrument frame. The instrumented bottom mount (Figure 1) allowed us to measure the nearbed turbulence, wave, and current hydrodynamics and the temporal evolution of ripples in the coarse wave orbital ripple domain on the seabed. An instrumented bottom mount was deployed in October just 3 days prior to the passage of hurricane Sandy. The frame and instruments survived the storm and recorded the waves, currents, and nearbed turbulence and was during our November post-Sandy cruise. The bottom mount consisted of the following instruments:

- 600 kHz upward looking ADCP with wave and current profiling capability
- 2.25 mHz Imagenex 881 rotary fanbeam sonar for timer-series measurements of bedform planview geometry
- 2 mHz Aquadopp HR current profiler (leased) for nearbed turbulence in the bottom boundary layer

The following sampling configuration was utilized during the deployment

RDI Workhorse Sentinel ADCP- was configured to measure profile of currents every 30 min and a 5-minute wave burst every hour Imagenex Rotary Sonar- 2 scans every hour set to a range of 4 m and 9 m respectively Aquadopp HR Profiler- burst sampling every hour for 5 min in HR configuration (8 Hz).

Data was recovered from both the ADCP and the PC-ADP and recorded significant wave heights of 7.4 m with attendant wave period of 14 seconds during the peak conditions of hurricane Sandy. A leak developed in the rotary sonar transducer head, which destroyed that instrument. The head was subsequently replaced and is currently deployed at the field site with recovery planned for Oct 1, 2013.

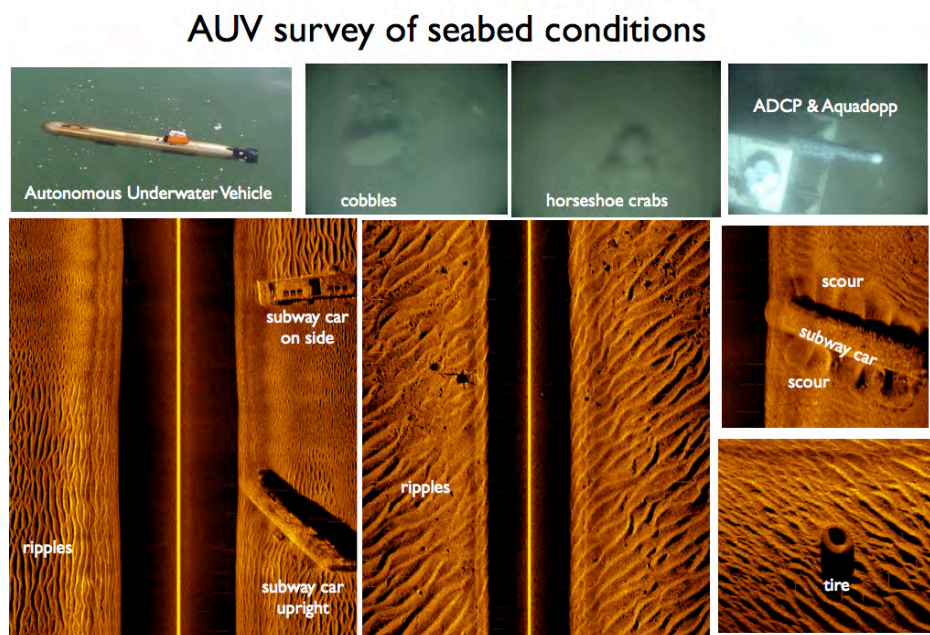


Figure 3. Repeat AUV surveys of the seabed included 900 kHz and 1800 kHz side-scan sonar and color still photos of the seabed.

AUV/ROV and SCUBA Dive Survey Component

Our objectives were to conduct repeat surveys of an ~1 km x 0.5 km subset of the offshore site with the AUV and the MBES, inspect and confirm our targeted mooring site with an ROV and then deploy an instrumented bottom mount. We successfully conducted repeated AUV surveys in October 2012, November 2012, March 2013, and July 2013. The AUV provided a useful platform for gathering very high-resolution side-scan sonar (900 kHz and 1800 kHz) acoustic images of the seabed that illustrate both the naturally occurring ripples and manmade objects on the seabed (Figure 3 lower panels). In addition to the acoustic data the AUV provided color photos of the seabed along the trackline, which allowed us to further identify and ground truth acoustic targets and to further quantify features on the seabed such as ripples, cobbles and boulders, and to confirm the orientation of our instrument frame at the time of deployment (Figure 3 upper panels). AUV and other instrumentation deployments were done primarily during daylight hours, with multibeam mapping typically conducted overnight during the field trials. For the AUV photo surveys, the missions were run at night to remove the influence of ambient light at these intermediate depths (~ 30 m) allowing the seabed to be illuminated strictly from the strobe light on the AUV.

On both our December 2012 and July 2013 cruises we also conducted ROV based target surveys using first a VideoRay ROV (December) and in July an Outland 1000 ROV. The ROVs provided a useful platform for detailed target inspection recording video and sonar of the ripples and subway cars and allowed us, in particular, to record the benthic conditions on the seabed and on the reef structures. Furthermore, during both the December 2012 and July 2013 cruises, scientific SCUBA diving was conducted. In our December 2012 cruise the EPA science dive team from Philadelphia lead by Steve Donohue came aboard and conducted a set of dives onto several Redbird subway cars in the field site. Conditions were challenging for diving as the water temperature and turbidity proved to be suboptimal, nevertheless valuable site characteristics were obtained. During the July 2013 cruise Trembanis and Dr. Mark Moline conducted 4 dives at the site including checking the condition and orientation of the deployed bottom mount instruments and an inspection of the scour and bedforms adjacent to several of the mapped subway cars. Conditions in July were much improved for SCUBA sampling with visibility of around 15 feet.

Fingerprint techniques for scour and ripple dynamics

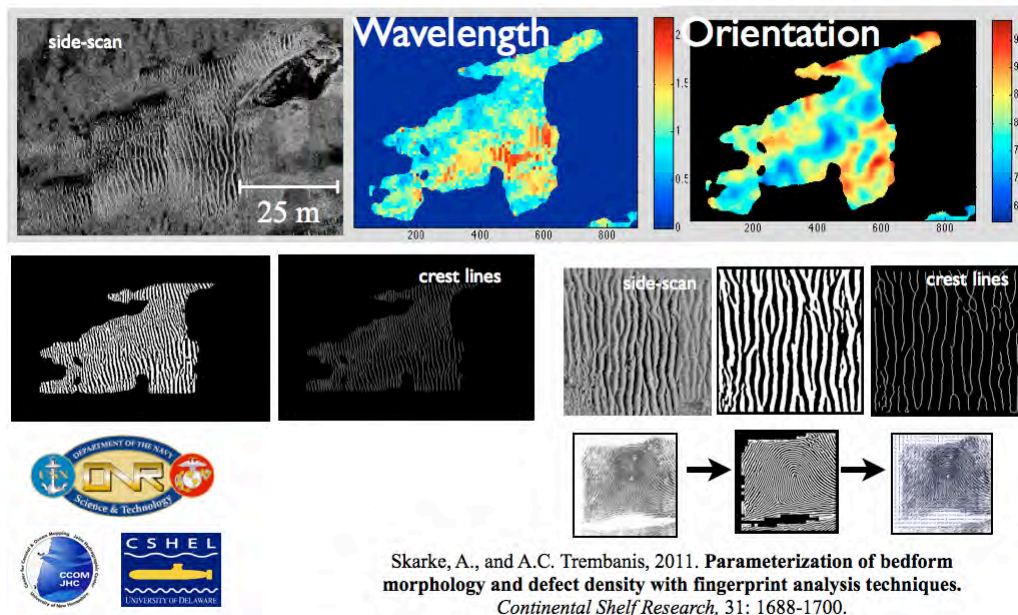


Figure 4. *The original fingerprint algorithm method has been adapted and modified by DuVal in this project to operate more effectively and efficiently over broad horizontal spatial domains. Above figure illustrates the application of the modified code to a rippled scour depression in the lee of a manmade object on the seabed.*

Finger print algorithm development

An extensive finger print ripple code tutorial and code enhancement has been completed allowing new users to quickly come up to speed on the work flow and algorithm outputs from the finger print code (Figure 1) for use in a variety of sonar image formats (i.e. side-scan mosaic, rotary sonar images, multibeam backscatter or DEM surface). Specifically this year MS student DuVal has adapted the code to provide improved computation performance and to provide spatial results extracting the bedform parameters (e.g. wavelength, orientation, and defect density) over a user selected cell size

applied over an entire AUV side-scan or MBES backscatter mosaic image (Figures 4 and 5). This process also preserves the inherent ripple/non-ripple filter step in the fingerprint algorithm and allows the user to quickly mask sonar images either for natural ripple features (Figure 5 lower left panel) or man-made object features (Figure 5 lower right panel).

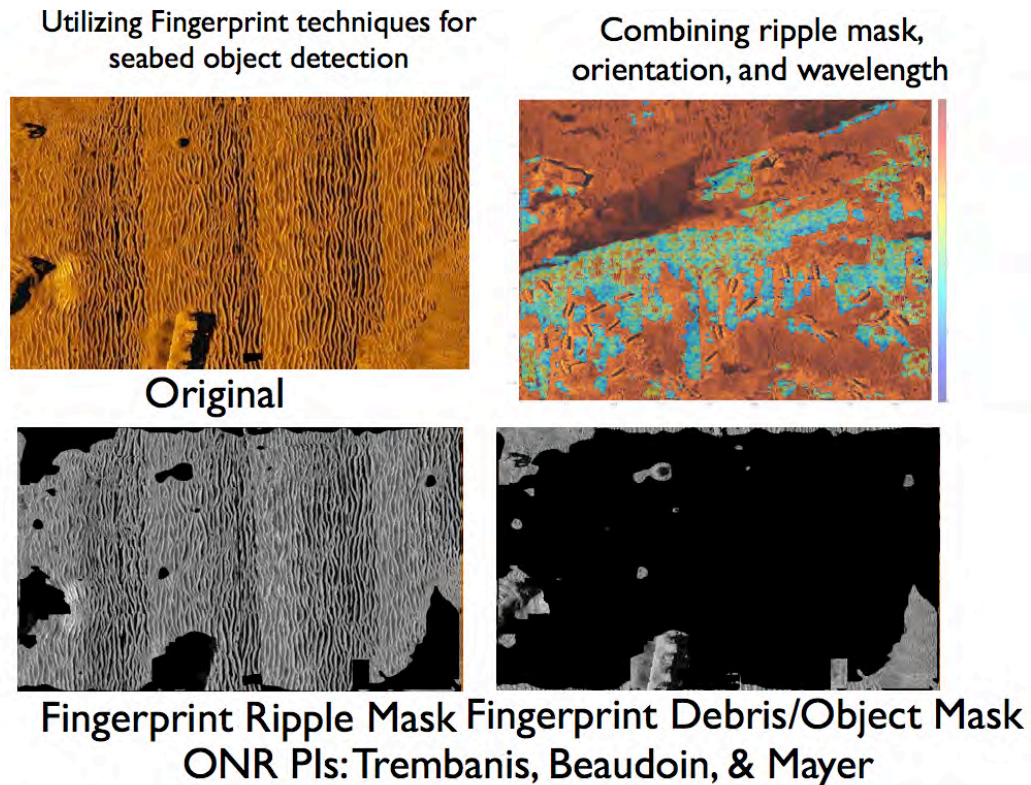


Figure 5. Implementation of the fingerprint ripple algorithm analysis (Skarke and Trembanis, 2011) utilizing high-resolution side-scan sonar data. 900 kHz side-scan sonar collected with the UD AUV from inner shelf Redbird Reef site during one of our repeated seafloor surveys. Fingerprint algorithm code modified by DuVal for this project to provide spatial masking and display of bedform parameters including wavelength, orientation, and defect density (upper right panel).

The fingerprint algorithm has been applied to each sonar dataset gathered. Specific control sites were chosen to monitor seabed ripple creation and evolution during the course of this study. Observations were made of the ripple fields 3 days prior to and 11 days following Hurricane Sandy. Furthermore, the subsequent decay of ripple bedforms were documented a month after Sandy and also following a large Spring Nor'easter with similar wave conditions to Sandy. Sorted bedform ripple fields underwent cyclical evolution from buried and inactive states to freshly generated ripples. Post-storm conditions led to decay of ripples and return to relict states, with ripples bedforms eventually undergoing burial. The fingerprint algorithm has provided pertinent ripple characteristic data to quantify these cyclical changes.

Cross-referencing the sediment sample data to *in situ* hydrodynamic wave and current data quantified the conditions required to initiate ripple formation at the artificial reef site. Conversely, relict ripple states measured by the fingerprint algorithm quantified the moments when ocean conditions dropped below threshold for ripple movement. Deviations were observed between

predicted and measured ripple wavelengths after Hurricane Sandy, with mean wavelengths above predicted threshold values based on several commonly used wave ripple models. This indicates that ripple bedforms may not immediately scale to instantaneous ocean conditions, but have a delayed response to sharp changes waves and currents (see Traykovski 2007). Furthermore, the fingerprint algorithm measured local variations in ripple wavelength and orientation across the study site. Increases in ripple defect density (e.g. bifurcations, terminations) were noted in ripples near reef objects, suggesting that objects may also affect ripple wavelength and orientation. Quantifying the effect of reef objects is currently an ongoing focus of M.S student DuVal's research.

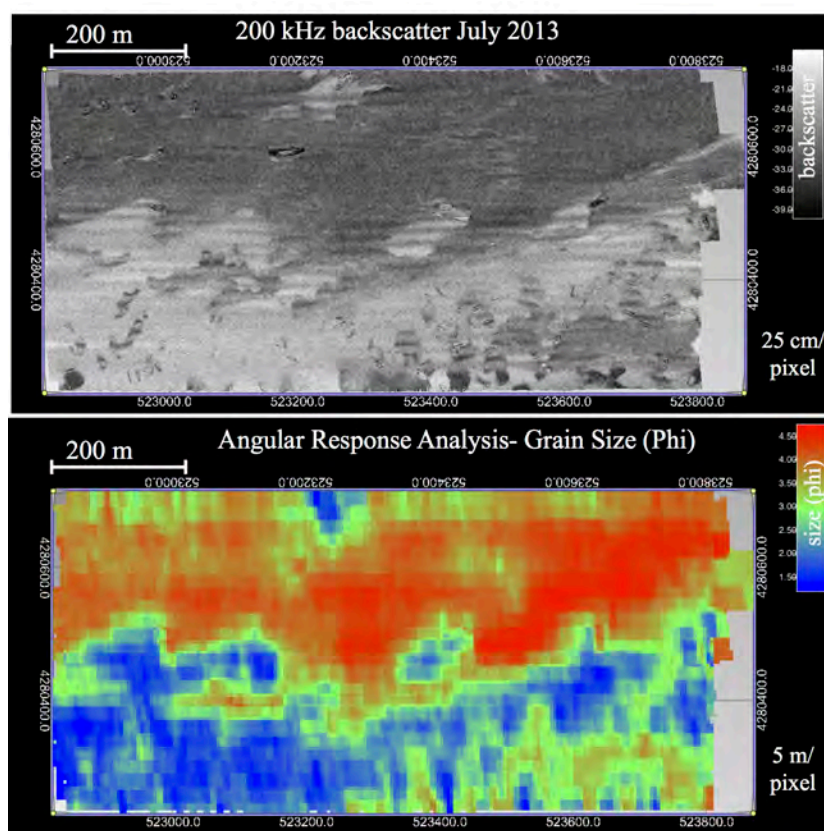


Figure 6. Preliminary results of Angular Response Analysis applied to July 2013 multibeam survey data.

Angular Response Analysis

The 7125 system's seabed imagery data can be processed to provide a seafloor backscattering strength mosaic, normalized to an incidence angle of $\sim 45^\circ$. If system calibrations and characteristics are well understood and compensated for the angular response of the seafloor over a range of incidence angles can be used to perform angular response analysis (ARA) in an attempt to more precisely characterize the nature of the seafloor and perhaps to even extract grain-size information (Fonseca and Mayer, 2007). Much of our early effort has focused on understanding the system behavior of the Reson 7125 MBES in use on the Sharp; having completed this, we have not applied an initial ARA analysis on the July 2013 cruise data (Figure 6). The preliminary ARA grain size estimation exhibits a close adherence to the backscatter gradations across the field site, an encouraging first result. These analyses were conducted in "patch mode" – i.e. analyzing the angular dependence over a swath of sea floor that is one-half of the full swath width wide. This approach provides data across the full range of

angular dependencies but limits the resolution of the analysis to a half swath width. Subsequent analysis in the remaining portion of the project period will focus on increasing the resolution of the analysis by first segmenting the data into much finer “themes” (Rzhanov et al, 2012) and comparison of the ARA analyses to the more than 50 sediment grab samples that were acquired to provide ground truthing.

IMPACT/APPLICATIONS

This project will enhance existing ONR sponsored Mine Burial and Mine Countermeasure research by incorporating additional detailed field observations utilizing sonar systems from both a surface ship and a small portable AUV. The application of the recently developed finger print algorithm technique for bedform parameterization (Skarke and Trembanis, 2011) to bedform characterization provides a novel tool for object detection with impact to mine countermeasures. This project also builds upon and extends previously sponsored ONR efforts (Mayer and Trembanis, 2008) to develop remote acoustic techniques (ARA- angular response analysis) for seafloor segmentation and classification. This project will also provide meaningful additional acoustic data, which will then be used by Trembanis and Mayer to specifically address the continued development of ARA techniques.

RELATED PROJECTS

This project builds off of our previous project ONR Award Number N00014-07-1-0666 Mayer and Trembanis, 2010. Following successful AUV field ripple surveys in 2009 in the vicinity of the Martha’s Vineyard Coastal Observatory we developed experience and protocols for both field operations and data analysis workflows to handle the integration and processing of the dense sonar data from the 500 kHz phase measuring bathymetric sonar. Both that project and our ongoing work in the existing grant have allowed us to further refine our ability to work with phase measuring bathymetric sonar and both have and will provide additional data for us to continue testing and expanding the frequency domain of the ARA (angular range analysis) work that will inform this and other site studies.

Another related project of note DE EPSCoR/DE Sea Grant. A recent Delaware EPSCoR project by PIs Luther, Trembanis, and Lipphardt provided the opportunity for us to deploy our ADCP at the Redbird site for a 4 week period gathering valuable background data of currents, waves, and salinity and temperature structure in the water column over the period from August 15-Sept 14, 2012. These data allow us to compare the *in situ* site measurements to both surface CODAR currents (Lipphardt) and to the nearest NDBC buoy #44009, which will allow us to compare the conditions at the site to the long-term record from the buoy. This initial deployment also allowed us to test the deployment configuration of the exact identical bottom mooring that we will be using in our Oct-Dec 2012 deployment.

Benthic Hardbottom Mapping in DE Bay- NOAA Sea Grant (Trembanis- Co-PI). This project first introduced us to the Redbird reef site offshore of Delaware Bay and allowed us to conduct reconnaissance surveys of the seabed in this area between 2008-2011. This project resulted in several publications and a PhD student project (N. Raineault completed Spring 2012).

PUBLICATIONS AND PRESENTATIONS OF RESULTS

A.C. Trembanis, C. DuVal, J. Beaudoin, V. Schmidt, D. Miller and L. Mayer, 2013. A detailed seabed signature from hurricane sandy revealed in bedforms and scour. *Geochemistry, Geophysics, Geosystems* Accepted manuscript online: 23 AUG 2013. DOI: 10.1002/ggge.20260

Schmidt, V., T. Weber, and A. Trembanis, 2012. Automated Optimal Processing of Phase Differencing Side-scan Sonar Data Using the Most-Probable Angle Algorithm. MTS/IEEE Oceans '12 Virginia Beach, VA.

PRESENTATIONS

A.C. Trembanis, 2013. Sandy's Fingerprint: Inner Shelf, Barriers, and Beach Nourishment. AAPG Annual Convention and Exhibition. Special invited session: hurricane sandy and our vulnerable developed coastlines (Eastern section SEPM). Pittsburgh May 21, 2013.

A.C. Trembanis, 2013. Benthic habitat and seafloor morphology mapping. Stony Brook University School of Marine and Atmospheric Sciences. Ocean and Atmosphere Colloquium Seminar May 10, 2013. <http://www.youtube.com/watch?v=cj3U3V23sJQ>

A.C. Trembanis, 2013. Impacts of Hurricane Sandy on the Delaware Inner Shelf- Observations of Bedform Dynamics and Scour from the Redbird Reef Site. Physical Ocean Science and Engineering Seminar, April 26, 2013

DuVal, C. and A.C. Trembanis, 2013. Object Scour and Bedform Dynamics at an Artificial Reef. Department of Geological Sciences Poster Seminar February 21, 2013.

Student Involvement:

While there was no direct student funding support in the project budget, this project has helped to facilitate several graduate students theses and involved participation by more than a dozen undergraduates through our research cruises. Specifically the following 4 graduate students theses involve some component of the project data: 1) Carter DuVal MS Oceanography UDel; 2) Trevor Metz MS Geology UDel; 3) Christopher Englert MS UNH; 4) Prasanna Kappannan PhD Mech Eng UDel

Collaborative Partners

This project has both built upon existing collaborations and lead to the development of new collaborations with the following colleagues- Doug Miller, University of Delaware; Bert Tanner, University of Delaware; Mark Moline, University of Delaware; Tobias Kukulka, University of Delaware; Doug Levin, Washington College; and Steve Donohue, EPA

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Rzhanov, Y., Fonseca L., and Mayer L. A., 2012 “Construction of Seafloor Thematic Maps from Multibeam Acoustic Backscatter Angular Response Data,” *Computers and Geosciences Journal*, v. 41, pp. 181-187.

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Skarke, A., Lipphardt Jr., B.L., Muscarella, P., Wong, K.C., A.C.Trembanis, Badiey, M., 2008. Comparison of HF radar and ADCP surface currents at the Delaware Bay mouth. Proceedings of the IEEE/OES/CMTC Ninth Working Conference on Current Measurement Technology, March 17-19, 2008, Charleston, SC.